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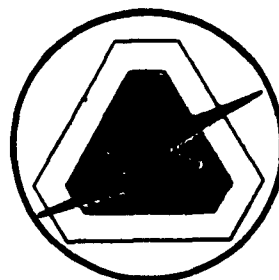
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USAEIRD Technical Report 2310

**TRANSIENT AND STEADY-STATE NUCLEAR RADIATION EFFECTS  
ON GERMANIUM PNP ALLOY TRANSISTORS**

**Edwin T. Hunter**

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**October 1962**

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**UNITED STATES ARMY  
ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY  
FORT MONMOUTH, N.J.**

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY  
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October 1962

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TRANSIENT AND STEADY-STATE NUCLEAR RADIATION EFFECTS  
ON GERMANIUM PNP ALLOY TRANSISTORS

Edwin T. Hunter

Harry E. Wannemacher

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ABSTRACT

Procedures and results of nuclear irradiations made on germanium alloy transistors are reported. The facilities used were the Penn. State University Reactor and the Sandia Pulsed Reactor. Transient results of  $I_{CBO}$  changes indicate dependence on applied voltage, with a resultant effective shunt resistance of 200 K. Changes in gain and in minority carrier lifetime were used to compute damage constants from data taken at both facilities. A factor of three is observed between the constants. Leakage current measurements and gain measurements are reported as functions of  $f\alpha$ .

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY

FORT MONMOUTH, NEW JERSEY

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# TRANSIENT AND STEADY-STATE NUCLEAR RADIATION EFFECTS ON GERMANIUM PNP ALLOY TRANSISTORS

## INTRODUCTION

Many groups of experimenters and theoreticians have, during the past several years, contributed much data and many theories concerning the effects of nuclear radiation on semiconductor devices, such as transistors or diodes. At first, most of these contributions concerned nuclear radiation in general, with no regard for the rate of delivery of the radiation to the devices under consideration. As time passed and more was learned about mechanisms of radiation damage, two separate types of studies began to develop; namely, exposures of devices to relatively low rate sources for lengthy periods of time, and exposures to very brief bursts of radiation with very high peak rates. The former types of studies were conducted, and still are being conducted, to observe at a leisurely pace what happens to create the so-called permanent damage effects. The latter variety of work being carried out is an effort to simulate what one might expect in the way of nuclear radiation from the detonation of a nuclear or thermonuclear type weapon.

Studies of this kind have resulted in a fair library of data and ideas. It has been our purpose during the past twelve months to plan experiments and acquire data to enable comparison of the effects observed on a given variety of transistors when exposed to the nuclear radiation environment extant in a power reactor (in this case the Pennsylvania State University 200 Kw facility) and to that found near a pulsed reactor (in this case the Sandia Pulsed Reactor Facility (SPRF)).

## EXPERIMENTAL PROCEDURE

### The Pennsylvania State University Reactor Experiments

The reactor facility available at Penn. State is of the swimming pool variety, capable of operation at a maximum power level of 200 Kw. At this level of operation, a target located underwater, and immediately adjacent to the reactor core, will be bombarded by a neutron flux of  $2 \times 10^{12} N_f v$  (neutrons/cm<sup>2</sup>-sec) with energies between 0.1 Mev and 10 Mev. In this report,  $N_f$  will refer to neutrons with energy  $> 0.1$  Mev. The total dose received can be obtained either by calculating it from the power level of the reactor and the time of exposure, or by using some selected threshold detector and the measured spectrum of the reactor. In our experiments, the former system was employed with an occasional check being made with sulfur threshold dosimeters.

The actual experimental arrangements used in the two experiments at Penn. State discussed in this report, if examined carefully, will show a great improvement from the first to the second. In general, the system

consists of a waterproof container, which houses the items under test, placed near the reactor core; a plastic tube containing the electrical connections from the submerged housing; the test circuitry, and a means of recording the information. In the first of these two experiments, the underwater container proved extremely awkward in that it was oriented horizontally and, being buoyant, quite difficult to lower on the instrument bridge. The plastic tubing used was heavy wall polyethylene, which became cracked during transit and tended to allow water to penetrate the system. These items did their job, but the system designed for the second experiment was much more efficient. For example, the container was oriented vertically and weighted with lead poured into the bottom. There was no problem whatever in lowering this tank to the bottom of the reactor pool. Also, the tubing used was lighter weight Tygon rather than polyethylene. Tygon will withstand the bending and rolling encountered in the laboratory and in transit.

The test circuits were basically the same in the two experiments; except that in the second one all devices not in the actual test circuit were switched to a common standby circuit which maintained d.c. bias on all such devices. During the first experiment, the devices were removed from the test circuit and left with no bias. In both experiments, the data was fed to a digital voltmeter with printout and recorded on printed tape. The devices under test were Ge alloy units arranged in a common base configuration, and the forward current transfer ratio  $\alpha$ , was monitored consecutively on all devices. Upon completion of a set of  $\alpha$  measurements, the emitter of the device under test was opened, and the collector-base leakage current  $I_{CBO}$  was monitored. Before and after measurements were also made on the effective minority carrier lifetime by the current injection technique described by Lederhandler and Giacoletto.<sup>1</sup> The nature of the data taken may be seen in Figure 1 showing  $\alpha$  vs.  $\Phi_p$  for the extremes of  $f_Q$ , the cutoff frequency, under investigation, and in Figure 2, which shows the variation in  $I_{CBO}$  with  $\Phi_p$ , again for the extremes in  $f_Q$ .

#### The Sandia Pulsed Reactor Facility

The Sandia reactor is a bare critical assembly providing a mixed neutron and gamma pulse of about 50 microseconds width at half maximum. At the screen, which is as near to the core as it is possible to locate, a target will be exposed to approximately  $10^{13}$  nvt (neutrons/cm<sup>2</sup>) with energies greater than 0.1 Mev, and about 2500 rads (H<sub>2</sub>O) from gamma rays. The neutron doses are measured by threshold dosimeters, mainly sulfur ( $E > 2.0$  Mev), with an occasional set of fission foils to keep a check on the spectrum. The gamma ray dose is measured by the Bausch & Lomb glass microdosimeter system. All of this dosimetry is provided by The Sandia Corporation. A more complete description of the Facility may be found in a Sandia Corp. monograph.<sup>2</sup>

The circuitry and recording equipment were set up in a trailer outside of the reactor building with the components being tested



mounted on a small chassis next to the reactor screen and connected to the trailer with approximately 150' lengths of RG-58 cable. Since the reactor pulse is very short, it is required to have a recording "channel" for each piece of information desired, and, as a result, the four oscilloscope traces can be utilized to record only three pieces of parametric data and one trace from a MgORAD to provide the pulse shape. For this reason, a much smaller quantity of data is available from the Sandia experiments than from Penn. State; however, some of this data is on the transient effects, about which there is currently great interest.

The devices under test were again germanium alloy units arranged in a common base configuration. In some of the tests,  $I_{CBO}$  was monitored with data being taken with different applied  $V_{CB}$ . In other tests, the output current,  $I_C$ , was monitored; however, circuit problems resulted in some rather unenlightening information in this area. The information was fed into oscilloscopes (Tektronix 555) and the resulting traces were photographed during the reactor burst. The transient  $I_{CBO}$  data is the most interesting transient information obtained in these experiments, and a plot of the peak change in  $I_{CBO}$  vs. the applied  $V_{CB}$  is shown in Figure 3. If one examines this data carefully and notes that the original values of  $I_{CBO}$  are much smaller than the transient values, a judicious application of Ohm's law reveals that there is a shunt resistance of approximately 200 K being dropped across the collector-base junction during the reactor burst. Pending closer study of other experimenters' data, it appears that this may possibly be an indicator that we are observing air ionization between leads inside the can, since 200 K is approximately the resistance of ionized air near the screen of the SPRF.

In an effort to compare SPRF produced effects with Penn. State produced effects, a set of transistors was placed on a plank which was laid radially outward from the reactor and left there for 16 pulses. In this manner a large dose was obtained, but with a much higher rate than at Penn. State. On these devices  $h_{FE}$  and  $\tau_e$  were measured for permanent change.

## RESULTS

The combined results of these previously described experiments can be presented in various forms. One form that is used rather prevalently is the relationship between  $\Delta\alpha$  and  $\Phi_f$ . Figure 4 shows data obtained from all of the experiments, broken into three separate categories according to  $f_\alpha$  of the devices. From these curves, it can be seen that there is greater damage, represented by greater changes in  $\alpha$ , at higher dose levels, and at lower values of  $f_\alpha$ . This is understandable when one considers the relation derived in the literature;<sup>3</sup>

$$f_\alpha = \frac{1.22}{\pi} \left( \frac{D_p}{W^2} \right) \quad (1)$$

where  $D_p$  is the diffusion constant for holes in the base of a pnp device

and  $W$  is the base width. If  $f_\alpha$  is high, then  $W$  must be narrower, thereby providing less volume in which lattice displacements can affect the passage of minority carriers, and, at the frequencies in question, the reduction in the minority carrier lifetime is the major cause of electrical degradation, manifested in the lowering of  $\alpha$ .

Now, let us consider the damage constants involved in these experiments. According to Webster<sup>4</sup>

$$\frac{1}{\beta} = \frac{SWA_s}{D_p A_e} + \frac{\sigma_b W}{\sigma_e L_{ne}} + \frac{W^2}{2L_{pb}^2} \quad (2)$$

where:  $\beta$  = common emitter forward current transfer ratio

$\sigma$  = conductivity

$A_e$  = area of the emitter junction

$A_s$  = effective surface recombination area around emitter

$L$  = diffusion length

$W$  = base width

$S$  = surface recombination velocity.

From equation (1) and the fact that

$$L_{pb}^2 = D_p \tau_p \quad (3)$$

we arrive at the equation:

$$\frac{W^2}{2L_{pb}^2} = \frac{1.22}{2\pi} \left( \frac{1}{f_\alpha} \right) \left( \frac{1}{\tau_p} \right) \quad (4)$$

which can be substituted into equation (2) to give:

$$\frac{1}{\beta} = \frac{SWA_s}{D_p A_e} + \frac{\sigma_b W}{\sigma_e L_{ne}} + \frac{1.22}{2\pi f_\alpha} \left( \frac{1}{\tau_p} \right). \quad (5)$$

Now, according to Loferski,<sup>5</sup> the surface recombination term and the emitter efficiency term are unchanging with radiation, at least relative to the bulk term, at the frequencies of interest. Therefore, we can examine the difference between Webster's equation before irradiation and after irradiation:

$$\frac{1}{\beta_f} - \frac{1}{\beta_i} = \frac{1.22}{2\pi f_\alpha} \left( \frac{1}{\tau_{pf}} - \frac{1}{\tau_{pi}} \right) \quad (6)$$

where the subscript i indicates initial conditions, and the subscript f indicates conditions after irradiation.

Relating  $\tau_{pf}$  to  $\tau_{pi}$  by the following:<sup>6</sup>

$$\frac{1}{\tau_{pf}} = \frac{1}{\tau_{pi}} + \frac{\Phi_f}{K} \quad (7)$$

where  $\Phi_f$  = total integrated neutron dose in neutrons/cm<sup>2</sup>, with energy greater than 0.1 Mev

and  $K$  = the damage constant.

Combining equations (6) and (7),

$$\frac{1}{\beta_f} - \frac{1}{\beta_i} = \frac{1.22}{2\pi f\alpha} \left( \frac{\Phi_f}{K} \right). \quad (8)$$

Lifetime changes are available on only some of the devices; however, on these, it is of interest to compare the values of  $K$  calculated directly from equation (7), which values will be referred to as  $K_r$ , and those calculated from equation (8), which values will be referred to as  $K_\beta$ . If the ratio,  $r_K$ , of  $K_\beta$  is computed for each of the fifteen devices

$\frac{K_\beta}{K_r}$  exposed at Sandia on which both lifetime and gain changes were recorded, and the results averaged, a value of  $r_K$  is obtained of  $3.2 \pm 1.7$ . On six devices exposed at Penn. State, the computed ratio is  $1.7 \pm 0.5$ . The constant that is generally referred to as the damage constant is  $K_r$ . Reference 6 gives a  $K$  for n-type Ge of  $5.0 \pm 2.0 \times 10^7$  Nvt-sec. The fact that the above difference exists between  $K_r$  and  $K_\beta$  may be explained by the fact that the injected carrier transport mechanism is not solely diffusion.

Some experimenters have indicated possible differences in amount of damage for the same radiation dose administered in different spectral distributions.<sup>7</sup> This problem arises because the dose is given in terms of all neutrons having  $E >$  some value which is not the damage threshold. Data taken during these experiments yield the following values of  $K_\beta$  averaged over the number of devices shown:

Penn. State Ept.	#1	8 Units	$(1.05 \pm 0.19) \times 10^8$	Nvt-sec.
Penn. State Ept.	#2	20 Units	$(2.1 \pm 0.8) \times 10^8$	Nvt-sec.
Sandia Ept.	#1	20 Units	$(5.2 \pm 2.2) \times 10^7$	Nvt-sec.
Sandia Ept.	#2	66 Units	$(3.5 \pm 1.3) \times 10^7$	Nvt-sec.

It is readily apparent that there is a significant difference in the  $K_\beta$ 's obtained in the two different environments. The two values obtained in one environment may be averaged, as can the other two, and then a ratio,  $r_{Env}$ , can be obtained. The data above yield a value of  $r_{Env} = 3.6 \pm 2.5$  by statistical error treatment. This factor is

attributed to the different dose rates of the two environments used. If one expressed the dose in terms of all neutrons with energy greater than 400 e.v., the factor would be even larger due to the spectral differences in the two environments.

The values of  $K$  calculated so far have been made on the basis of an actual constant existing. No further calculations will be made, but it may be of interest to note that, as shown in Figure 5, the values of  $K_T$  as calculated from Sandia data have somewhat of a dependence on the total neutron flux. Figure 6, showing data on  $K_T$  taken at two different total exposures at Penn. State show an opposite dependence on total dose. An attempt to explain the significance of these observations will not be made at this time.

### CONCLUSIONS

The conclusions reached are applicable to the particular family of devices on which these data were collected, i.e., germanium alloy, PNP devices with a range of  $\tau_Q$  from 3.3 mc. to 13.2 mc. The conclusions are as follows:

1. Permanent gain degradation is inversely proportional to  $f_Q$ .
2. Permanent increase in  $I_{CBO}$  is directly proportional to  $f_Q$ .
3. Transient increases in  $I_{CBO}$  are directly proportional to the applied voltage,  $V_{CB}$ , indicating a shunt resistance of 200 K.
4. The damage constants calculated from changes in minority carrier lifetimes are approximately one-third the value of the constants calculated from changes in  $\beta$ . This indicates that in the units under study, the injected carrier transport mechanism is not solely diffusion.
5. The damage constants obtained on devices exposed at Penn. State were about three times as large as those obtained on devices exposed at Sandia. This indicates that three times as much permanent damage was done by the high-rate pulsed radiation received at Sandia as was done by the same dose of low-rate radiation received at Penn. State. If the total dose is expressed as all neutrons having energy greater than 400 ev., rather than 100 Kev., this factor would be still larger, since the PSU spectrum is richer in low energy neutrons than is the SPRF spectrum.

### ACKNOWLEDGEMENTS

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use of their facilities. Some of the original suggestions leading to this set of experiments were made by Mr. Frederick Gordon, Jr., Deputy Chief, S & M Branch.

#### REFERENCES

1. Lederhandler, S. R. & Giacoletto, L. J., "Measurement of Minority Carrier Lifetime and Surface Effects in Junction Devices," Proc. IRE, Vol. 43, pp. 477-483, April 1955.
2. Colp, J. L. & O'Brien, P. D., "The Sandia Pulsed Reactor Facility," Sandia Corp. Monograph SCR-229, August 1960.
3. Hunter, L.P., Handbook of Semiconductor Electronics, McGraw-Hill, 1956, Chapter 4, p.23.
4. Webster, W.M., "On the Variation of Junction Transistor Current Amplification Factor with Emitter Current," Proc. IRE, Vol. 42, pp. 914-920, June 1954.
5. Loferski, J.J., "Analysis of the Effect of Nuclear Radiation on Transistors," J. Applied Physics 29, 35 (Jan. 1958).
6. Messenger, G.C. & Spratt, V.P., "The Effect of Neutron Irradiation on Germanium and Silicon," Proc. IRE, Vol. 46, Nr. 6, June 1958, pp. 1038-1044.
7. Contract Report ASD TR 61-511 from Litton Systems, Inc., under Contract AF 33 (600)-41452.

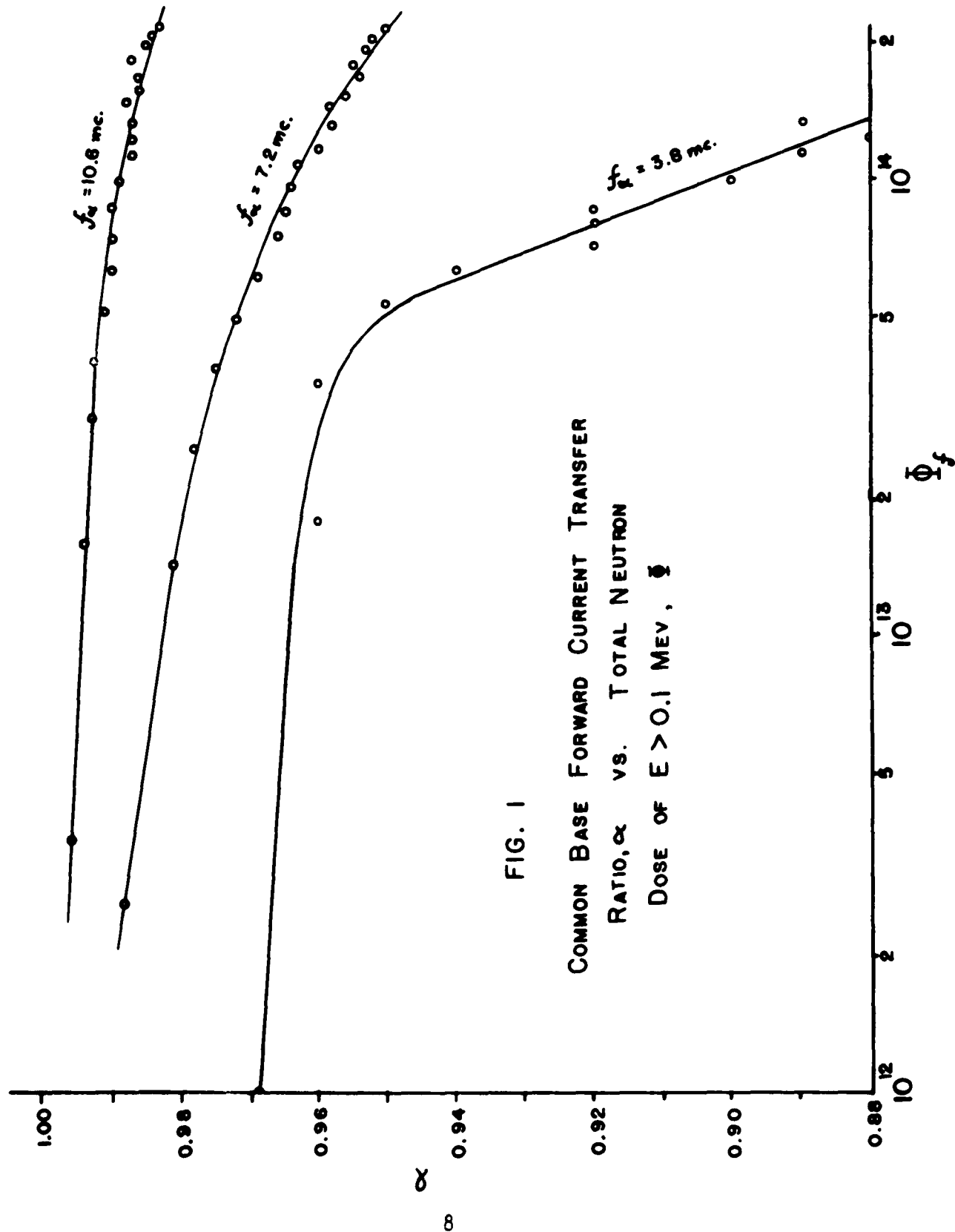
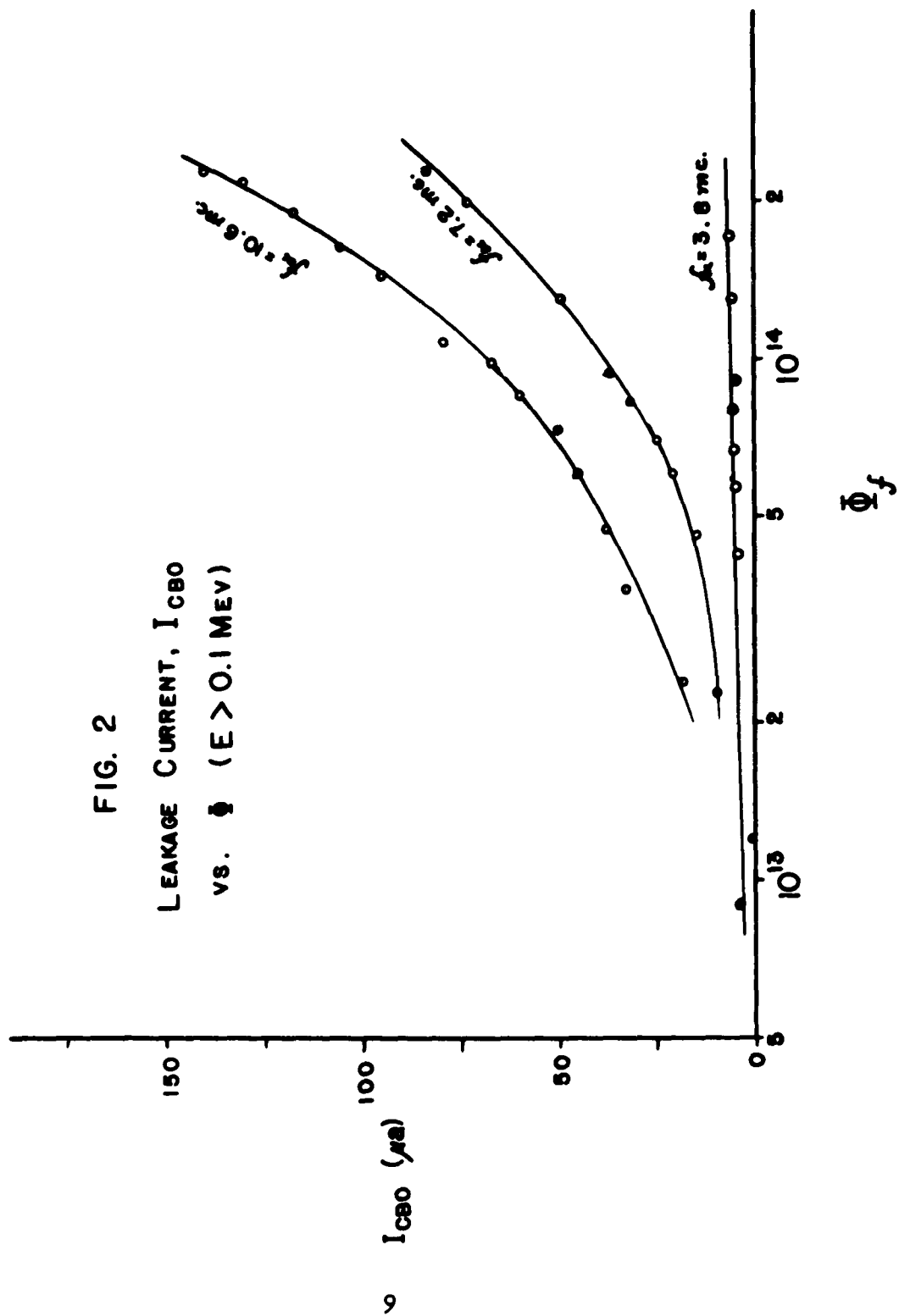
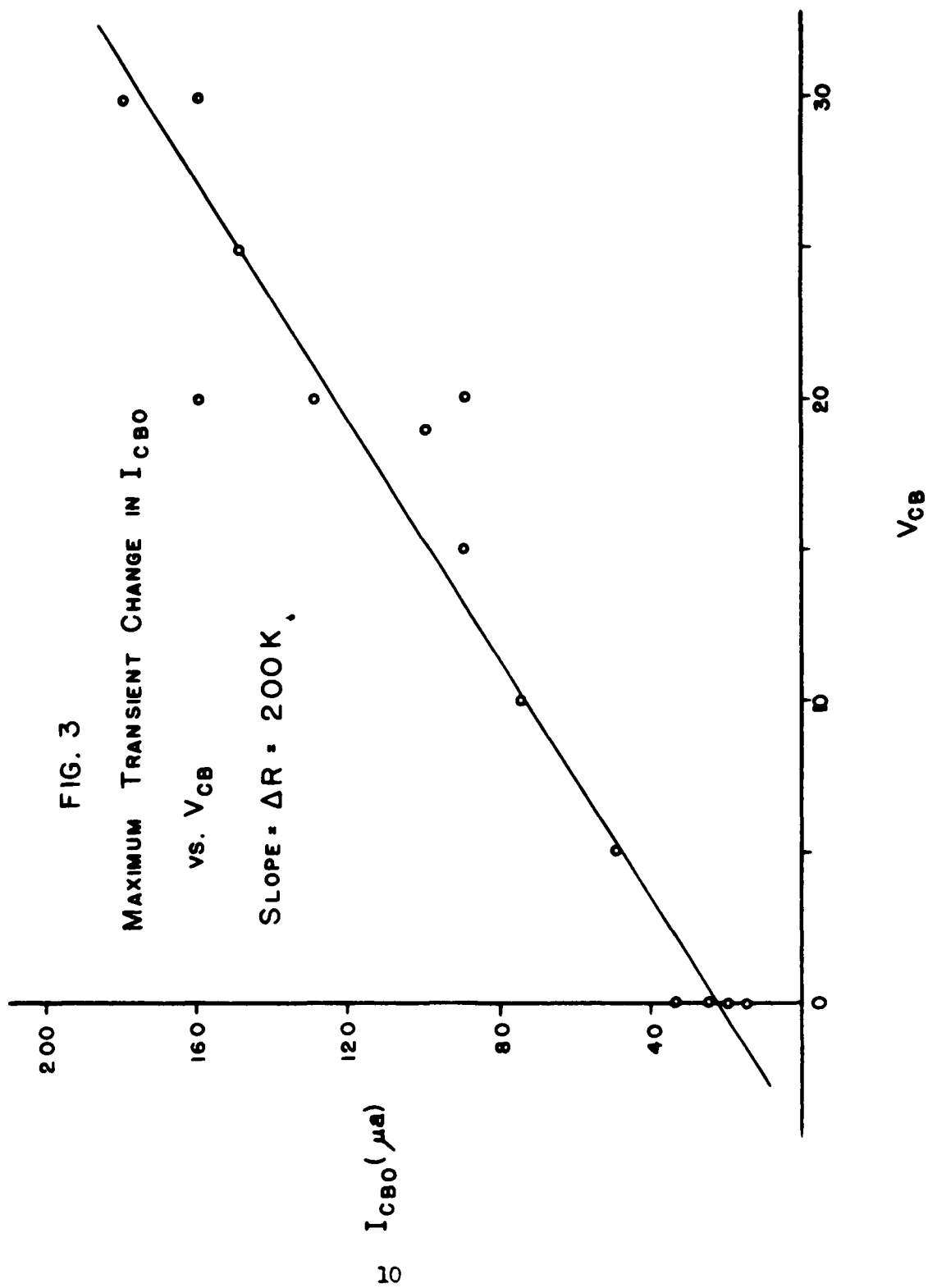


FIG. 2  
LEAKAGE CURRENT,  $I_{CB0}$   
vs.  $\Phi$  ( $E > 0.1 \text{ MeV}$ )







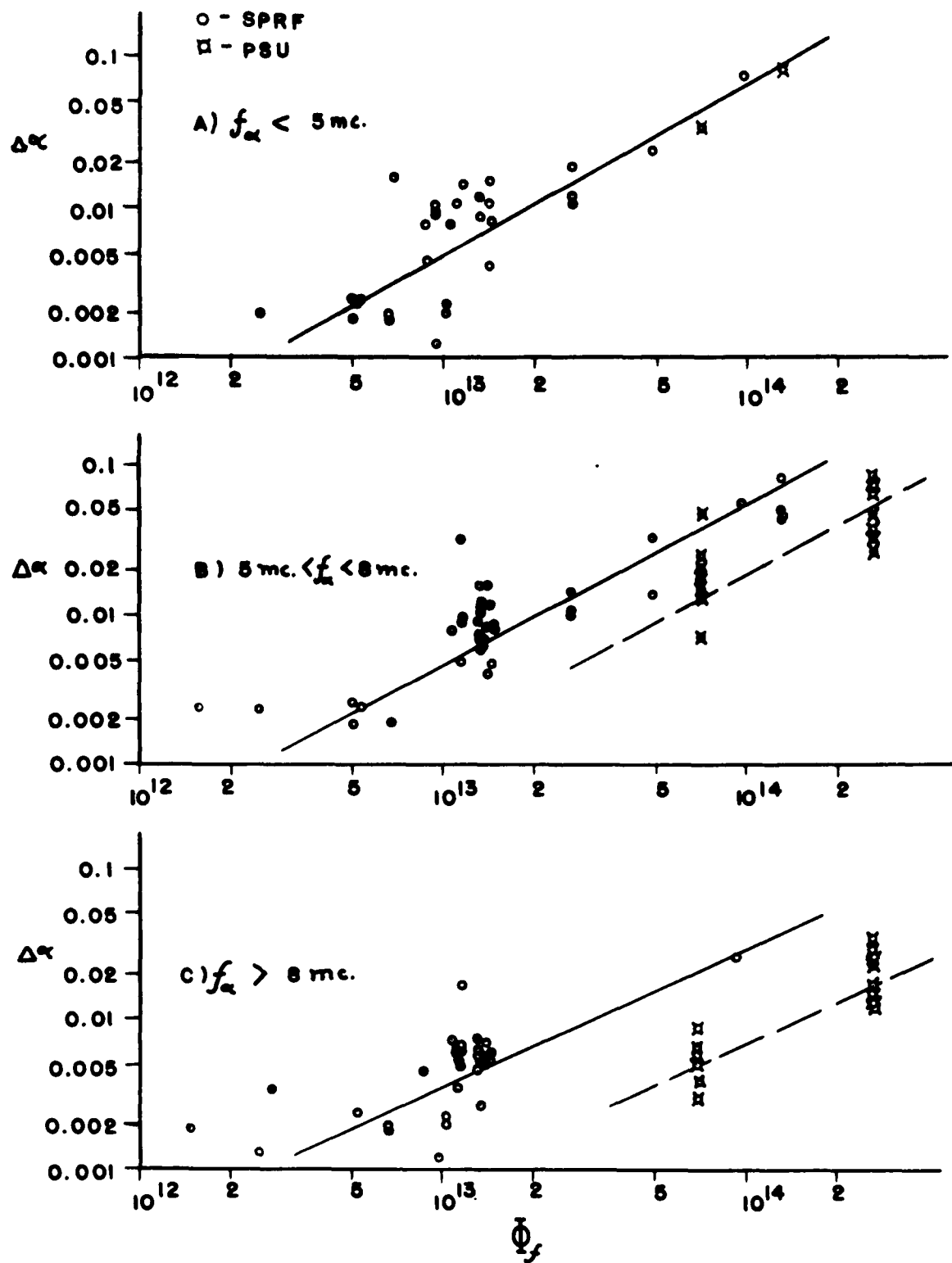


FIG. 4. DEGRADATION IN  $\alpha$  VS.  $\Phi_f$

FIG. 5  
DAMAGE CONSTANT, K, vs.  $\Phi_f$

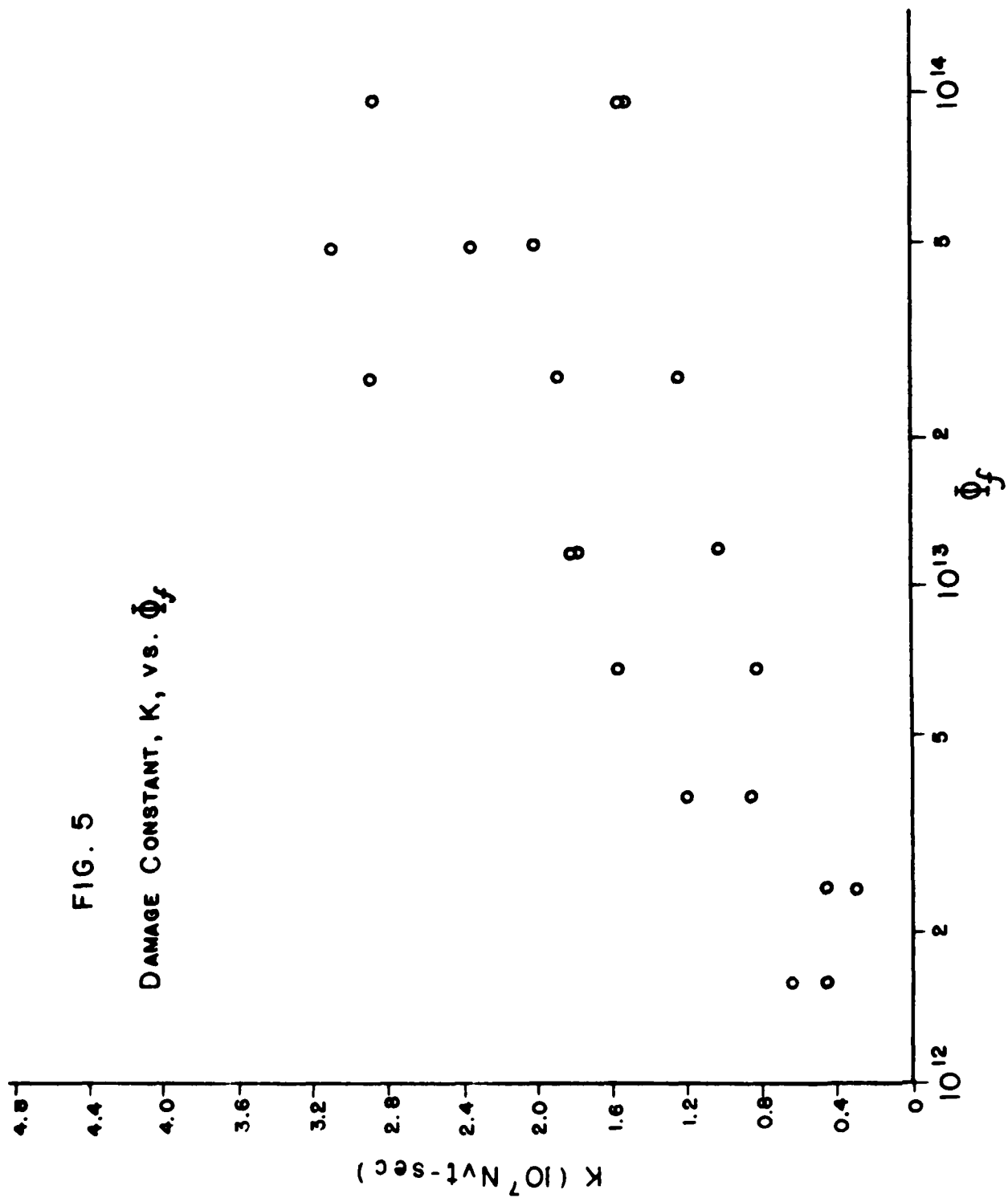
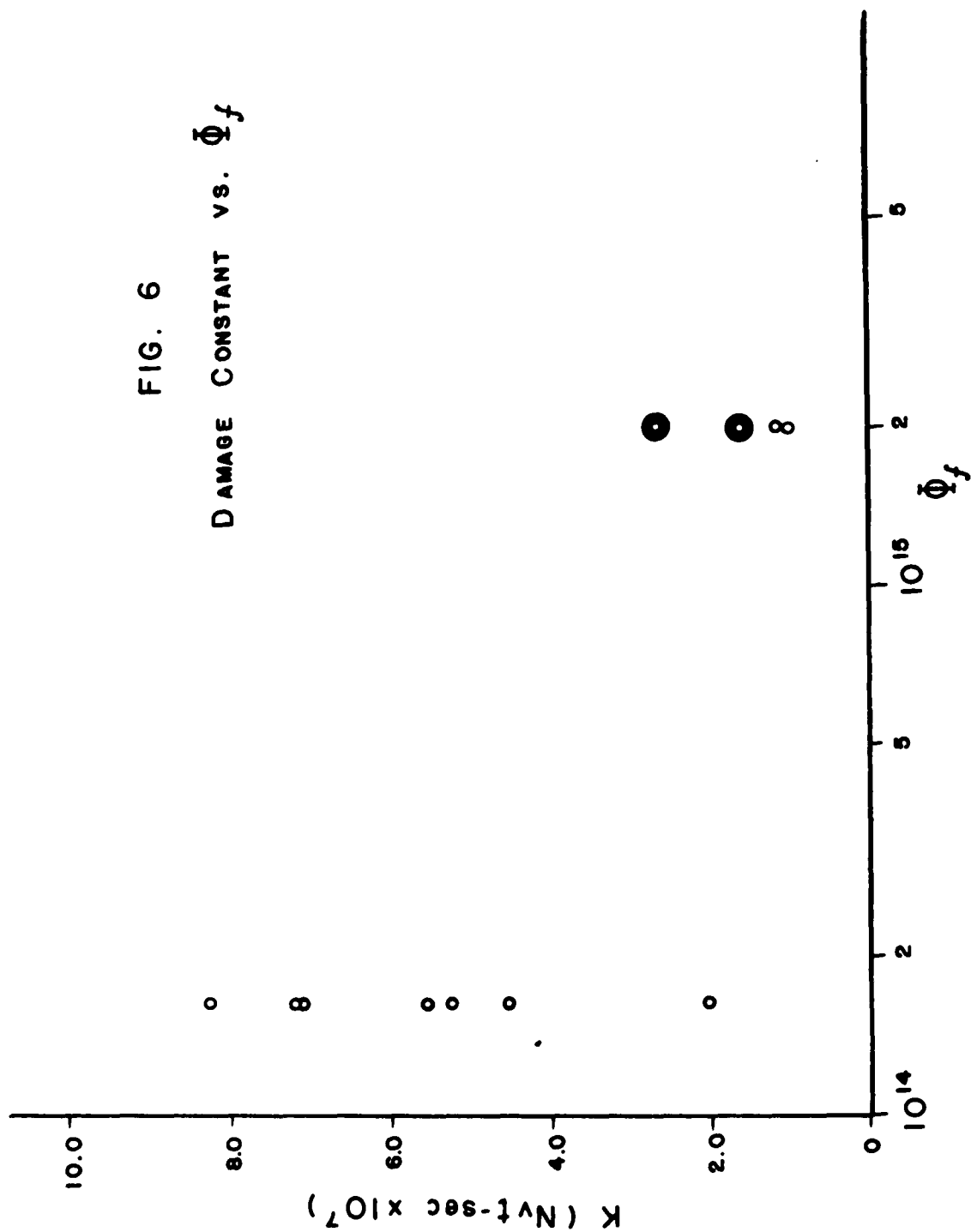


FIG. 6  
DAMAGE CONSTANT VS.  $\Phi_f$



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TRANSIENT AND STEADY-STATE NUCLEAR RADIATION EFFECTS ON GERMANIUM PNP ALLOY TRANSISTORS by Edwin T. Hunter and Harry E. Wannemacher October 1962, 13 p. incl. illus., 7 refs. (USAEIRD L Technical Report 2310) (DA Task 3A99-21-001-01) (DASA Task OST-74-00-005-26)			TRANSIENT AND STEADY-STATE NUCLEAR RADIATION EFFECTS ON GERMANIUM PNP ALLOY TRANSISTORS by Edwin T. Hunter and Harry E. Wannemacher October 1962, 13 p. incl. illus., 7 refs. (USAEIRD L Technical Report 2310) (DA Task 3A99-21-001-01) (DASA Task OST-74-00-005-26)		
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